(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
29 December 2005 (29.12.2005)

PCT

(10) International Publication Number
WO 2005/125287 A2

(51) International Patent Classification[7]: H05H 1/24, A61B 18/00

(21) International Application Number: PCT/NL2005/000434

(22) International Filing Date: 14 June 2005 (14.06.2005)

(25) Filing Language: Dutch

(26) Publication Language: English

(30) Priority Data:
1026422 15 June 2004 (15.06.2004) NL

(71) Applicant *(for all designated States except US)*: TECHNISCHE UNIVERSITEIT EINDHOVEN [NL/NL]; Den Dolech 2, NL-5612 AZ Eindhoven (NL).

(72) Inventors; and

(75) Inventors/Applicants *(for US only)*: STOFFELS-ADAMOWICZ, Eva [BE/BE]; Turnhoutsebaan 90, B-5470 Retie (BE). FRANKEN, Martijn [NL/NL]; Prunellapad 31, NL-5643 BW Eindhoven (NL). STEINBUCH, Maarten [NL/NL]; Medevoort 7, NL-5707 DD Helmond (NL). VAN DER LAAN, Ewout, Peter [NL/NL]; Stellenboschstraat 130, NL-5642 GM Eindhoven (NL).

(74) Agents: VALKONET, Rutger et al.; Algemeen Octrooi-en Merkenbureau, P.O. Box 645, NL-5600 AP Eindhoven (NL).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SM, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LT, LU, MC, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:
— *without international search report and to be republished upon receipt of that report*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

WO 2005/125287 A2

(54) Title: DEVICE FOR CREATING A LOCAL PLASMA AT THE LOCATION OF AN OBJECT

(57) Abstract: The invention relates to a device for creating a local cold plasma at the location of an object, said device at least comprising a high-frequency power source, a plasma chamber, a plasma discharge electrode disposed in said plasma chamber, which is electrically connected to said high-frequency power source, as well as a supply line for a plasma gas, which opens into the plasma chamber at a location near the plasma discharge electrode. The object of the invention is to provide an improved device as referred to in the introduction, which enables an improved control of the created plasma in relation to the object. To that end, the device according to the invention is characterized in that the device comprises adjusting means arranged for automatically orienting the plasma discharge electrode relative to the object.

Device for creating a local cold plasma at the location of an object.

DESCRIPTION

The invention relates to a device for creating a local cold plasma at the location of an object, said device at least comprising a high-frequency power source, a plasma chamber, a plasma discharge electrode disposed in said plasma chamber, which is electrically connected to said high-frequency power source, as well as a supply line for a plasma gas, which opens into the plasma chamber at a location near the plasma discharge electrode.

A device of the above kind is known, for example from US patent No. 5,977,715. Said patent specification discloses a hand-held device by means of which a (cold) plasma can be locally applied to an object. The known device is characterized by a limited manoeuvrability and consequently a limited controllability of the created plasma at the location of the object.

Consequently, the object of the invention is to provide an improved device as referred to in the introduction, which enables an improved control of the created plasma in relation to the object. To that end, the device according to the invention is characterized in that the device comprises adjusting means arranged for automatically orienting the plasma discharge electrode relative to the object.

More in particular, according to the invention the adjusting means comprise at least one sensor for determining the current orientation of the plasma discharge electrode relative to the object, the adjusting means being arranged for orienting the plasma discharge electrode on the basis of the current position as determined.

Said at least one sensor may be arranged for measuring the power returned by the created plasma, which returned power is a measure of the current orientation of the plasma discharge electrode relative to

the object.

The adjusting means are arranged for orienting the plasma discharge electrode on the basis of the current position as determined, whilst in the case of a specific measuring principle according to the invention said adjusting means are arranged for orienting the plasma discharge electrode by comparing the returned power with the power being transported to the plasma discharge electrode by the high-frequency power source.

These aspects of the device according to the invention enable a precise orientation of the created plasma relative to the object with which the plasma is to react.

In a first embodiment, the adjusting means may comprise at least one stepping motor or DC motor. On the other hand, the adjusting means may comprise at least one memory metal or at least one voice coil.

In a functional embodiment, which enables an adequate orientation of the plasma relative to the object, the adjusting means are arranged around the plasma discharge electrode.

A special embodiment of the device according to the invention comprises a catheter built up of an outer jacket, a proximal end and a distal end, which catheter can be introduced into a human or animal body with the distal end thereof, in which distal end of the catheter at least the plasma discharge electrode is mounted.

Since the distal end of the catheter furthermore forms the plasma chamber, this embodiment makes it possible to create a plasma close to tissue or an organ in the human or animal body in a very effective and controllable manner, which renders the device more universally usable, for example for medical treatments in the body of a human being or an animal.

In the embodiment in which the device is not a catheter, the device with the plasma chamber is disposed outside the body of a human being or animal, in direct proximity to the skin or to an external

organ, so that said embodiment is very suitable for carrying out cosmetic treatments (scar tissue removal).

In order to position the created plasma sufficiently close to the object (tissue or an organ), the distal end of the catheter is at least partially open.

More specifically, a coaxial transmission line made up of an inner conductor and an outer conductor coaxially arranged round said inner conductor is provided in the catheter for driving the plasma discharge electrode, with the plasma discharge electrode being electrically connected to the high-frequency power source via said inner conductor.

Likewise, the supply line for the plasma gas may extend within the outer conductor in the catheter so as to make it possible to generate the plasma in an effective and advantageous manner near the distal end of the catheter. More specifically, the outer conductor forms the outer jacket of the catheter in that case.

In another functional embodiment, the supply line for the plasma gas is located outside the outer conductor in the catheter, with the supply line for the plasma gas being coaxially arranged around the outer conductor. For reasons of strength, one or more spacers may be provided between the outer jacket and the outer conductor in this embodiment.

In a special embodiment, the catheter may furthermore be a dilatation catheter, which makes it possible to carry out treatments in a body lumen, such as the treatment of deposits in a blood vessel.

More specifically, the plasma discharge electrode may be made of a hard metal, for example W or Ti, in which case the plasma discharge electrode may be provided with a layer that reduces the operating voltage, for example Al_2O_3.

Furthermore, the plasma gas used in the device according to the invention may be a gas mixture built up of He/O_2, He/N_2 or N_2O.

In another functional embodiment of the device according to the invention, the flexible filiform element comprises an electrical conductor that electrically connects the plasma discharge electrode present at the free end of the flexible filiform element to the high-frequency power source.

More specifically, the electrical conductor is accommodated in an elongated recess in the flexible filiform element, which elongated recess has been formed in the flexible filiform element by means of a lithographic process, and which electrical conductor has been provided in the recess by means of a sputtering process.

To create a plasma in a more effective manner, the free end of the plasma discharge electrode has a pointed shape.

In another embodiment, the pointed free end of the plasma discharge electrode is conical in shape.

A functional embodiment of the device according to the invention is furthermore characterized in that the apex angle of the pointed free end of the plasma discharge electrode is maximally 30°.

The diameter of the flexible filiform element is furthermore maximally 0.1 mm.

The invention will now be explained in more detail with reference to a drawing, in which:

Figures 1-8 show various embodiments of a device according to the invention.

For a better understanding of the invention, like parts will be indicated by identical numerals in the description of the figures below.

Figure 1 discloses a device for creating a local cold plasma at the location of an object.

In this figure, the device for creating a local cold plasma is embodied as a catheter 10 having a proximal end 10a and a distal end 10b. The catheter 10 is intended for medical applications, as it can be

inserted into a lumen in the body of a human being or an animal. Said lumen may be the trachea, for example, or the anal opening or a blood vessel. In this embodiment the catheter 10 has been inserted into a blood lumen 11 (a vein or an artery) with the distal end 10b thereof.

The catheter 10 comprises a coaxial transmission line 13 made up of an inner conductor 14 and an outer conductor 15 coaxially surrounding said inner conductor. The inner conductor 14 electrically connects a plasma discharge electrode 16 to a high-frequency power source 4. Present between the inner conductor 14 and the outer conductor 15 is a dielectric 13a, which functions to prevent the transmission of voltage between the two conductors 14-15. The device according to the invention furthermore comprises a supply unit 5 for a plasma gas, which plasma gas can be transported in the direction of a plasma chamber 9, near the plasma discharge electrode 16, via a suitable supply line (not shown).

The catheter 10 is furthermore embodied as a dilatation catheter, since the distal end 10b is provided with a dilatation balloon 12, which can be inflated with a medium, using suitable means (not shown), so that the balloon 12 is supported against the inner side of the wall 11a of the lumen 11. The wall 11a may be the wall of a blood vessel, for example. The medium used for inflating the dilatation balloon 12 is supplied from the supply unit 5 to the balloon 12 via a supply line 20 in the coaxial transmission line 13.

By driving the plasma discharge electrode 16 with suitable supply or voltage pulses from the high-frequency voltage source, via the inner conductor 14, a plasma 17 is created in the gas mixture supplied by the supply unit 5 at the location of the plasma discharge electrode 16, which plasma locally reacts with or acts on the object to be treated, in this case the inner side of the wall 11a of the lumen 11. The energy that is released from the plasma 17 can be used for treating cancer cells, for example, or other disorders.

According to the invention, the device comprises adjusting

means 6, which are arranged for orienting the plasma discharge electrode 16 relative to the object, in this case the wall 11a of the lumen 11. More specifically, said adjusting means 6 comprise at least one sensor for determining the current orientation of the plasma discharge electrode 16 relative to the object. Said at least one sensor 7 is preferably disposed near the plasma discharge electrode 16 on the distal end 10b of the catheter 10. To achieve a more precise orientation, several sensors 7 may be used so as to obtain a three-dimensional orientation relative to the object.

The adjusting means 6 are preferably arranged for orienting the plasma discharge electrode 16 on the basis of the current position of the plasma discharge electrode 16 as determined by said at least one sensor 7. To that end, the signal generated by the sensor 7, which is representative of the current orientation in the three-dimensional plane of the plasma discharge electrode 16 relative to the object (in this case the wall 11a of the lumen 11), is fed back to the adjusting means 6 via a suitable communication line, in which adjusting means 6 said orientation is compared to the desired orientation of the plasma discharge electrode 16.

On the basis of said feedback and the difference that may have been found to exist between the desired orientation and the current orientation as determined by the sensor 7, the adjusting means 6 will be energized in such a manner that the plasma discharge electrode 16 will be positioned in the desired orientation relative to the object.

In the embodiment as shown in figure 1, the adjusting means 6 comprise at least one stepper motor or DC motor, which impose a translating or rotating motion on the catheter 10 or on the coaxial transmission line 13. In particular the latter embodiment, in which the transmission line 13 is rotated or translated relative to the catheter 10 together with the plasma discharge electrode 16, is preferred, because the dilatation balloon 12 will thus remain immovable within the lumen 11.

Unhoped-for movement of the catheter 10 and the dilatation balloon 12 would lead to painful friction contact between the dilatation balloon 12 and the wall 11a of the lumen 11, which may cause damage or injury.

As the translation and rotation arrows in figure 1 show, it is thus possible to orient the plasma discharge electrode 16 relative to the object to be treated (in this case the wall 11a of the lumen 11). This makes it possible to obtain "real-time" images of the objects and the plasma discharge electrode 16, using imaging techniques not shown (for example ultrasound), on the basis of which the reorientation of the plasma discharge electrode 16 can be verified.

In another embodiment, as shown in figure 2, the adjusting means 6' comprise one or more elements 18a, 18b consisting of memory metal, which are connected to the adjusting means 6' via suitable lines 19a-19b. A suitable orientation of the plasma discharge electrode 16 relative to the object 11a to be treated can also be effected by means of the driving elements 18a-18b (memory metal), using a suitable voltage or current signal (delivered by the adjusting means 6').

In this embodiment, too, the current position or orientation of the plasma discharge electrode 16 relative to the object to be treated is determined by means of one or more sensors 7, which to that end deliver suitable signals to the adjusting means 6', on the basis of which a possible difference with the desired orientation is detected. The adjusting means 6- will drive the driving elements 18a-18b-18c on the basis of said difference, causing the distal end 10b of the coaxial transmission line 15 to deform, thus adjusting the plasma discharge electrode 16 and thus the location of the plasma 17 as created.

As figure 2 also shows, it is preferable to use at least three driving elements 18a-18b-18c, which are arranged symmetrically around the plasma discharge electrode 16 on the distal end 10b of the transmission line 13. By individually controlling the various driving elements 18a-18c built up of memory metal it becomes possible to impose a

random orientation in the three-dimensional plane on the distal end 10b, and thus on the plasma discharge electrode 16, relative to the object 11a.

Figure 3 shows an additional aspect of the invention, in which the distal end 10b of the catheter 10 forms the plasma chamber 9. In this embodiment, the external dimensions of the coaxial transmission line 13 are also the external dimensions of the catheter 10. By providing the distal end 10b with several openings 22 it becomes possible to allow the plasma 17 created in the plasma chamber 9 to escape from the distal end 10b of the catheter 10 and thus exert its influence on the nearby or surrounding object (body tissue).

The outer surface 15 of the catheter 10 also functions as an earthing for the coaxial transmission line 13. To that end, the material indicated at 13 is a dielectric medium. The outer surface 15 may form an earthing layer for controlling the high-frequency power source 4 (as shown in figures 1 and 2).

Figure 4 shows another embodiment of the device according to the invention, in which the supply line 20 for the plasma gas as supplied by the gas supply unit 5 (figures 1 and 2) coaxially surrounds the coaxial transmission line 13-14-15. To effect an adequate supply of the plasma gas from the supply unit 5 in the direction of the plasma chamber 9 at the plasma discharge electrode 16, several spacers 21 are disposed between the coaxial outer conductor 15 and the outer surface 10 of the catheter.

In this embodiment, too, the distal end 10b of the catheter, which forms the plasma chamber 9, is provided with several openings 22 so as to allow the plasma 17 at the plasma discharge electrode 16 to exert its effect in the direction of the object to be treated.

In yet another embodiment as shown in figure 5, the supply line 20 for the plasma gas from the gas supply unit 5 is incorporated in

the dielectric 13a of the transmission line 13.

Figure 6 shows the general principle of the device according to the invention, in which the plasma discharge electrode 16 that is disposed in the plasma chamber 9 generates a plasma, in particular a cold plasma, at the location of an object (not shown).

The plasma discharge electrode 16 is driven by means of a transmission line 13, which electrically connects the plasma discharge electrode 16 to a high-frequency power source 4. The device is also provided with a gas supply unit 5, which carries a plasma gas into the plasma chamber 9 via a supply line 20.

According to the invention, the device for creating a local cold plasma at the location of an object is provided with adjusting means 6, 18a-18c, which are arranged for orienting the plasma discharge electrode 16 relative to the object (not shown). To that end, the device is fitted with at least one sensor 7, which determines the current orientation of the plasma discharge electrode 16 and transmits a related signal via a signal line 7' to a processing unit 6a that forms part of the adjusting means 6.

The processing unit 6a compares the current position as measured by the sensor 7 of the plasma discharge electrode 16 to a desired position and generates a control signal on the basis thereof, which signal drives the adjusting means 6 to correct the difference as determined and impose a different orientation on the plasma discharge electrode 16 relative to the object that is to be treated with the plasma. The adjusting means 6 may be embodied as discussed in the detailed description above.

In another embodiment as shown in figure 7, a sensor 7 is disposed outside the plasma chamber 9. The sensor 7 functions to measure the returned (or reflected) power from the plasma chamber 9. Said returned power is transmitted to the sensor 7 in the form of an electrical signal via the connection 7' and is a measure of the distance

from the plasma 17 to the object to be treated. The sensor 7 carries the electrical signal (which is a measure of the returned power) to the processing unit 6-6a, 18a-18c, where the signal is compared to the driving power delivered to the plasma chamber 9 by the high-frequency power source 4.

Thus, the orientation of the plasma discharge electrode 16 (and the plasma 17) relative to the object can be determined in a quick, precise but above all a simple manner and, if necessary, said orientation of the plasma discharge electrode 16 can be corrected.

In all embodiments, the plasma discharge electrode 16 may be made of a hard metal, for example W or Ti, with the plasma discharge electrode 16 possibly being provided with a layer (not shown) that reduces the operating voltage, e.g. Al_2O_3.

In another embodiment, in which the device is not a catheter, the device with the plasma chamber 9 is disposed outside the body of a human being for an animal in direct proximity to the skin or to an external organ, so that said embodiment is very suitable for carrying out cosmetic treatments (scar tissue removal). In this embodiment, the object to be treated is not a body lumen but a person's skin, and the device is used for removing or treating birthmarks or scar tissue. Furthermore, the device according to the invention may also be used for treating human beings or animals for caries or dental plaque.

In figure 8 another embodiment of a device according to the invention is shown. In this embodiment, the plasma discharge electrode 16 forms part of a flexible, filiform element 10 made of an electrically non-conducting material. The flexible filiform element 10 comprises an electrical conductor 14, which electrically connects the plasma discharge electrode 16 mounted on the free end of the flexible filiform element 10 to the high-frequency power source 4. The diameter of the flexible filiform element element 10 is maximally 0.1 mm, so that this embodiment is suitable for generating plasmas on a microlevel at the location of the

tip end 16a of the plasma discharge electrode 16 for treating tissue at cell level.

The functionality of the use of a flexible material for the element 10 is that the microcatheter 10 thus obtained can be bent, so that it can also be inserted into small passages in the human or animal body, such as blood vessels.

In this specific embodiment, the electrical connection by means of the electrical conductor 14 between the high-frequency power source 4 and the plasma discharge electrode 16 is realised in that a recess 30 is present in the elongate, flexible filiform element, in which recess the conductor 13 can be arranged.

More specifically, the recess 30 has been formed in the flexible filiform element 10 by means of a lithographic process, and subsequently the electrical conductor has been arranged in the recess, using a sputtering process, in particular a metal sputtering process, so as to realise the electrical connection between the plasma discharge electrode 16 and the high-frequency power source 4 in this manner.

Analogously to the above-explained embodiments, the device according to figure 8 is also provided with adjusting means arranged for orienting the plasma discharge electrode 16 relative to the object (not shown). Correspondingly, the current position as measured on the basis of the power returned from the plasma discharge electrode 16 is used for detecting any differences and realising a correction in the position of the plasma discharge electrode 16 on the basis thereof.

To realise a sufficiently high electrical field near the free end 16a of the plasma discharge electrode 16, the end 16a must be configured to have a pointed or a conical end. In both cases the apex angle of the pointed end 16a must be maximally 30°. Depending on the usability and the application, the apex angle must be even more acute.

This specific embodiment can moreover be used without supplying a plasma gas. Assuming that the electrical field near the free

end 16a of the plasma discharge electrode 16 is high enough, a plasma discharge will be initiated in air or even under water. Using this embodiment, it is thus possible to approach specific tissues or cells in a simpler manner than with the embodiment that comprises a plasma gas supply unit.

CLAIMS

1. A device for creating a local cold plasma at the location of an object, said device at least comprising

a high-frequency power source,

a plasma chamber,

a plasma discharge electrode disposed in said plasma chamber, which is electrically connected to said high-frequency power source, as well as

a supply line for a plasma gas, which opens into the plasma chamber at a location near the plasma discharge electrode, **characterized in that** the device comprises adjusting means arranged for automatically orienting the plasma discharge electrode relative to the object.

2. A device according to claim 1, **characterized in that** the adjusting means comprise at least one sensor for determining the current orientation of the plasma discharge electrode relative to the object.

3. A device according to claim 2, **characterized in that** said at least one sensor is arranged for measuring the power returned by the created plasma, which returned power is a measure of the current orientation of the plasma discharge electrode relative to the object.

4. A device according to claim 2 or 3, **characterized in that** the adjusting means are arranged for orienting the plasma discharge electrode on the basis of the current position as determined.

5. A device according to claim 4, **characterized in that** said adjusting means are arranged for orienting the plasma discharge electrode by comparing the returned power with the power being transported to the plasma discharge electrode by the high-frequency power source.

6. A device according to any one or more of the preceding claims, **characterized in that** the adjusting means may comprise at least one DC motor.

7. A device according to any one or more of the preceding

claims, **characterized in that** the adjusting means comprise at least one memory metal.

8. A device according to any one or more of the preceding claims, **characterized in that** the adjusting means comprise at least one voice coil.

9. A device according to any one or more of the preceding claims, **characterized in that** the adjusting means are arranged around the plasma discharge electrode.

10. A device according to any one or more of the preceding claims, **characterized in that** the device comprises a catheter built up of an outer jacket, a proximal end and a distal end, which catheter can be introduced into a human or animal body with the distal end thereof, in which distal end of the catheter at least the plasma discharge electrode is mounted.

11. A device according to claim 10, **characterized in that** the distal end of the catheter forms the plasma chamber.

12. A device according to claim 11, **characterized in that** the distal end of the catheter is at least partially open.

13. A device according to any one or more of the claims 10-12, **characterized in that** a coaxial transmission line made up of an inner conductor and an outer conductor coaxially arranged round said inner conductor is provided in the catheter for driving the plasma discharge electrode, with the plasma discharge electrode being electrically connected to the high-frequency power source via said inner conductor.

14. A device according to claim 13, **characterized in that** the supply line for the plasma gas extends within the outer conductor in the catheter.

15. A device according to claim 14, **characterized in that** the outer conductor forms the outer jacket of the catheter.

16. A device according to claim 13, **characterized in that** the supply line for the plasma gas is located outside the outer conductor in

the catheter.

17. A device according to claim 16, **characterized in that** the supply line for the plasma gas is coaxially arranged around the outer conductor.

18. A device according to claim 16 or 17, **characterized in that** one or more spacers are provided between the outer jacket and the outer conductor.

19. A device according to any one or more of the claims 10-18, **characterized in that** the catheter is a dilatation catheter.

20. A device according to any one or more of the preceding claims, **characterized in that** the plasma discharge electrode is made of a hard metal, for example W or Ti.

21. A device according to any one or more of the preceding claims, **characterized in that** the plasma discharge electrode is provided with a layer that reduces the operating voltage; for example Al_2O_3.

22. A device according to any one or more of the preceding claims, **characterized in that** the plasma gas is a gas mixture built up of He/O_2, He/N_2 or N_2O.

23. A device according to any one or more of the preceding claims, **characterized in that** the plasma discharge electrode forms part of a flexible filiform element made on an electrically nonconducting material.

24. A device according to claim 23, **characterized in that** the flexible filiform element comprises an electrical conductor that electrically connects the plasma discharge electrode present at the free end of the flexible filiform element to the high-frequency power source.

25. A device according to claim 24, **characterized in that** the electrical conductor is accommodated in an elongated recess in the flexible filiform element.

26. A device according to claim 25, **characterized in that** the elongated recess has been formed in the flexible filiform element by

means of a lithographic process, and in that the electrical conductor has been provided in the recess by means of a sputtering process.

27. A device according to any one or more of the claims 23-26, **characterized in that** the free end of the plasma discharge electrode has a pointed shape.

28. A device according to claim 27, **characterized in that** the pointed free end of the plasma discharge electrode is conical in shape.

29. A device according to claim 27 or 28, **characterized in that** the apex angle of the pointed free end of the plasma discharge electrode is maximally 30°.

30. A device according to any one or more of the claims 23-29, **characterized in that** the diameter of the flexible filiform element is maximally 0.1 mm.

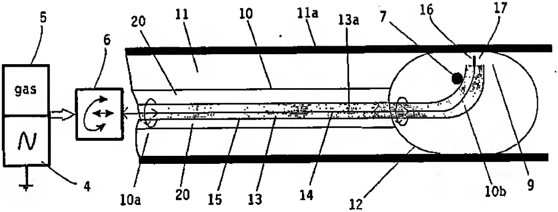
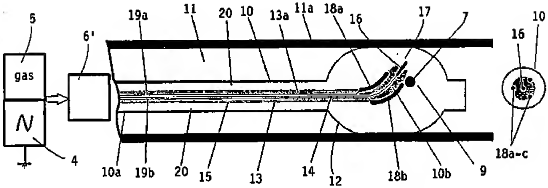


Fig. 1



5
gas
6'
19a
11
20
10
13a
11a
18a
16
17
7
10
16
4
10a
19b
20
15
13
14
12
18b
10b
9
18a-c

Fig. 2

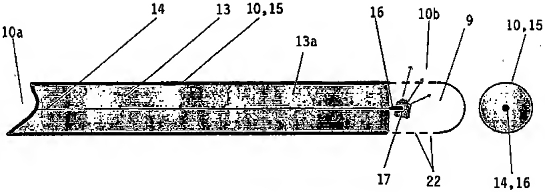


Fig. 3

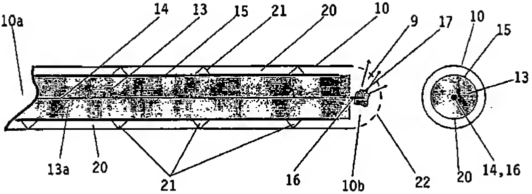


Fig. 4

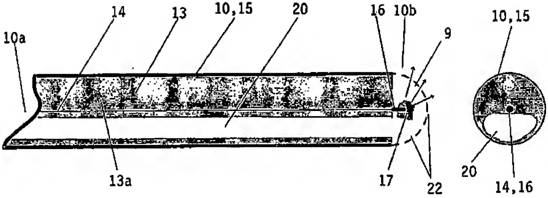


Fig. 5

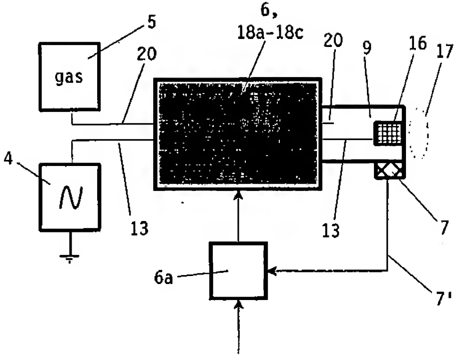


Fig. 6

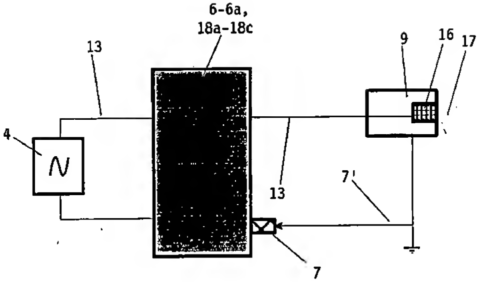


Fig. 7

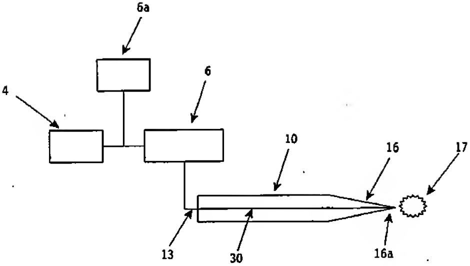


Fig. 8